EDGE Project

Operating Envelopes: Calculation Architecture and Objective Functions

Prof Luis(Nando) Ochoa

Dr Michael Z. Liu

Network Advisory Group

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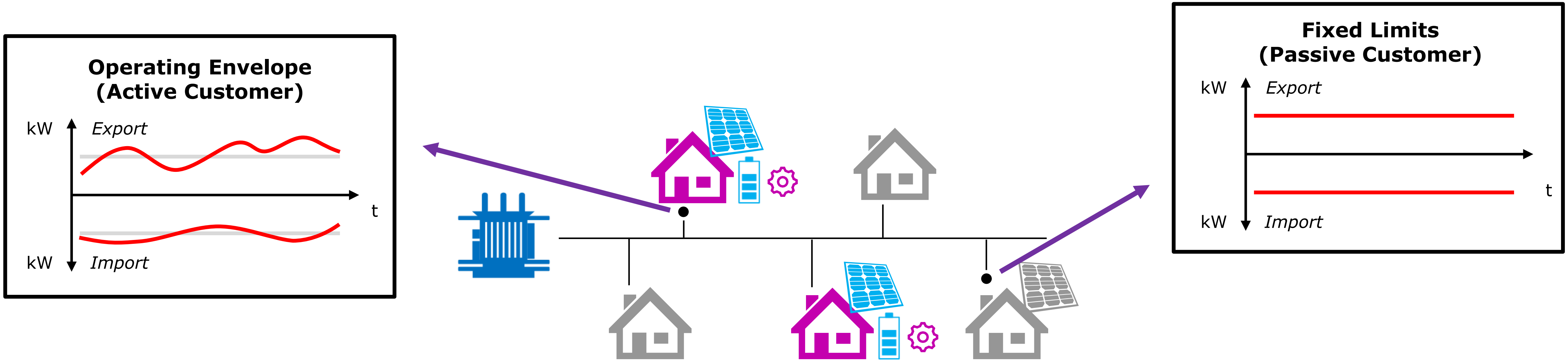
Outline

- (Some) Definitions
- Topic 1: Operating Envelopes – Calculation Architecture
- Topic 2: Operating Envelopes – Objective Functions (Allocation Methodology)

(Some) Definitions

- **Active Customer**: Customer engaged with an aggregator
- **Passive Customer**: 'Normal' customer with or without DER
- **Operating Envelopes (OEs)**: Time-varying export/import limits* at the network connection point of active customers

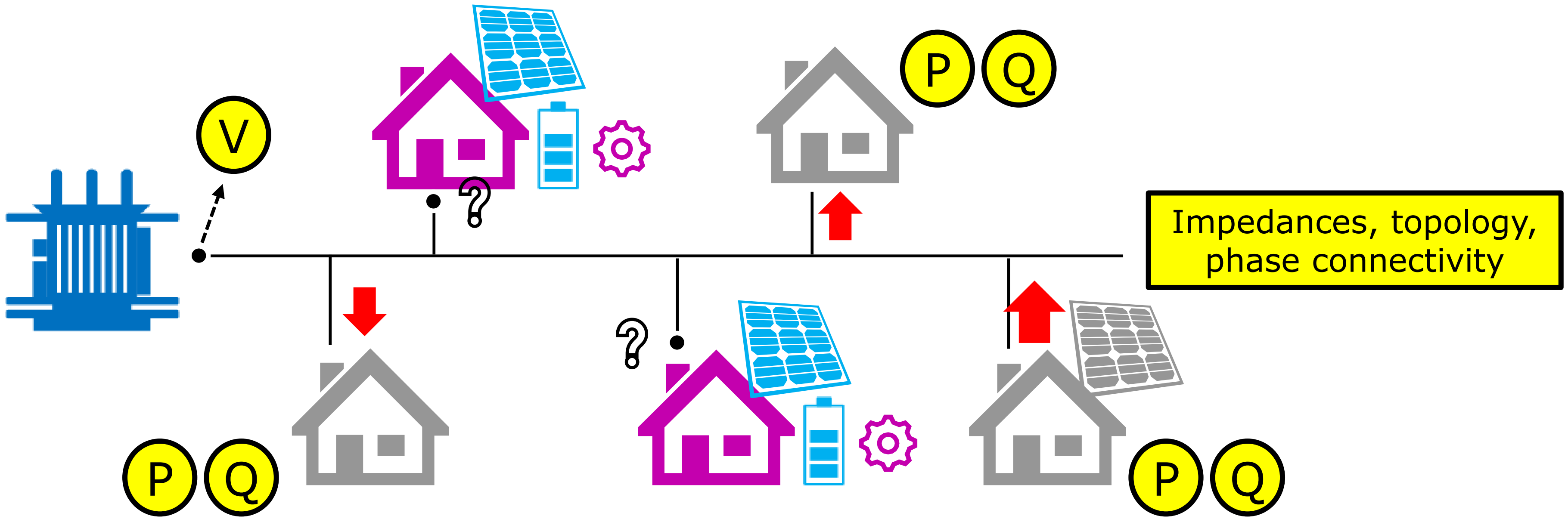


* First year of EDGE, OE focus is on active power. No reactive power services.

Topic 1:
Calculation Architecture

Key Input Data to Calculate OEs

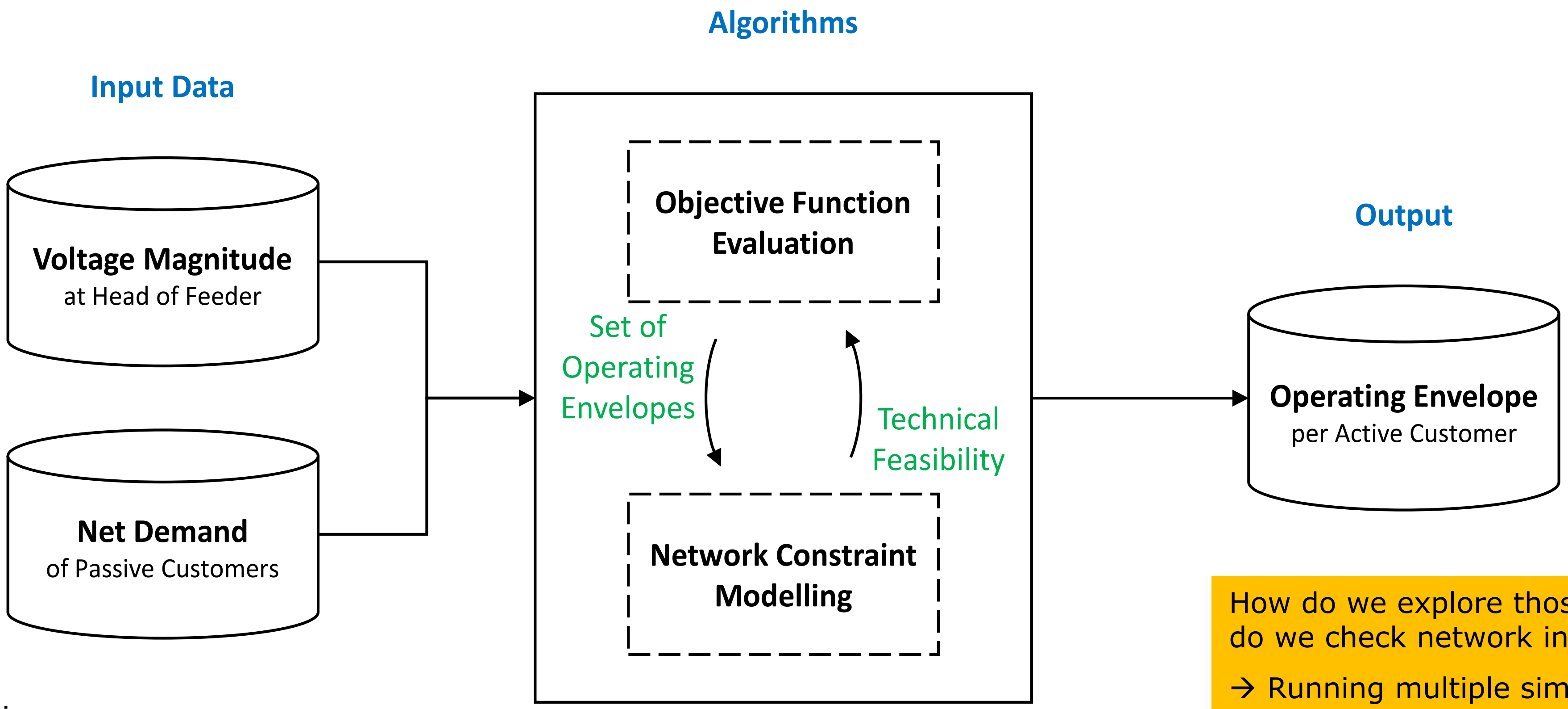
- To calculate the OEs we need to know the state of the rest of the network
  - ✓ Full three-phase network model
  - ✓ Net demand (P, Q) of passive customers (derived from smart meter data)*
  - ✓ Voltage magnitudes (V) at head of feeder



* First year of EDGE, Q of active customers is also considered.

Generic Architecture to Calculate OEs

- For a given interval*, the OEs are calculated by exploring different states of the network that capture the possible exports/imports of active customers and that also ensure network integrity**.



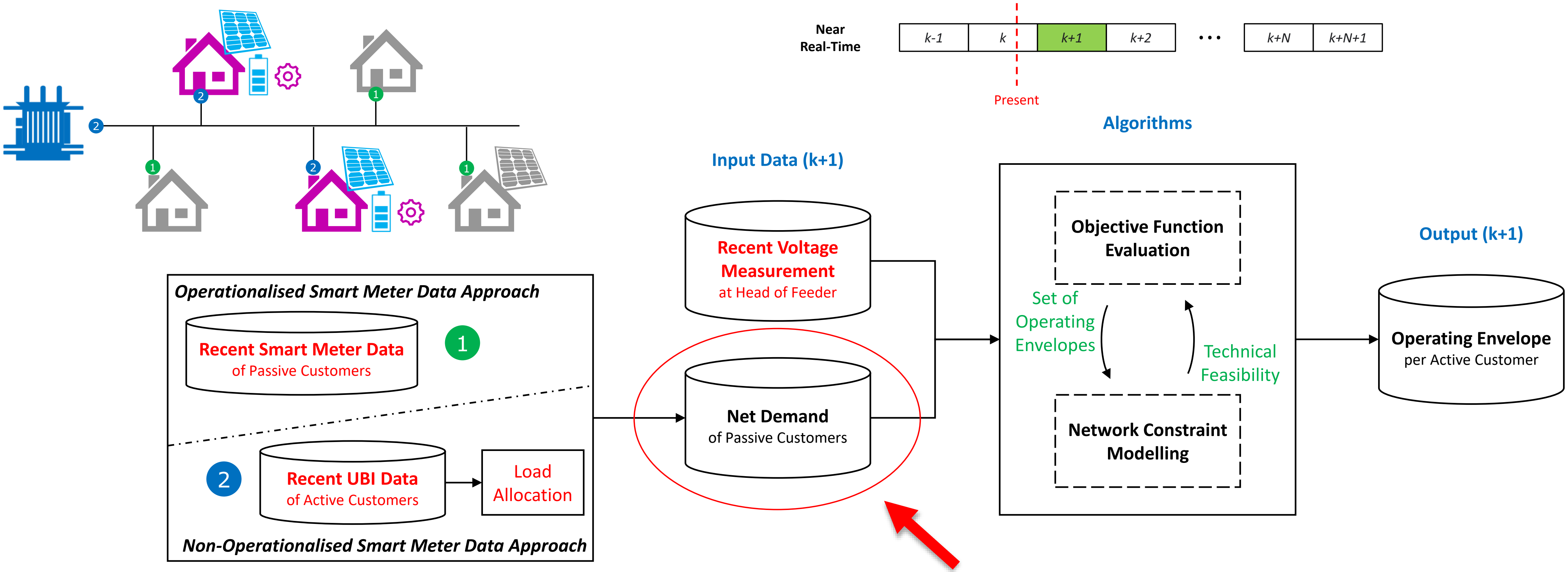
How do we explore those states and how do we check network integrity?

→ Running multiple simplified power flows

* Every 5, 15, 30 min.
** Voltages and currents within limits.

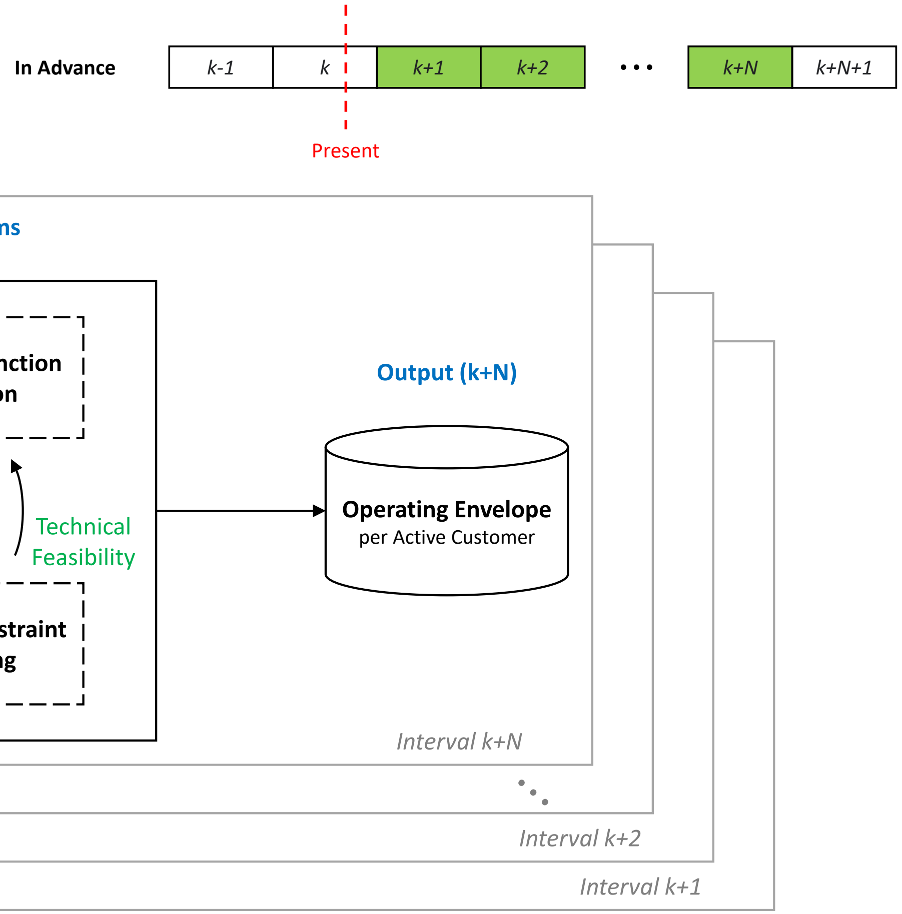
Near Real-Time Architecture

- OEs are calculated for the upcoming interval and based on recent measurements
  - How to obtain *net demand of passive customers (P and Q)* is key



In-Advance Architecture

- OEs are calculated for multiple intervals in the future and based on forecasted data
  - *Obtain accurate forecasts are key*



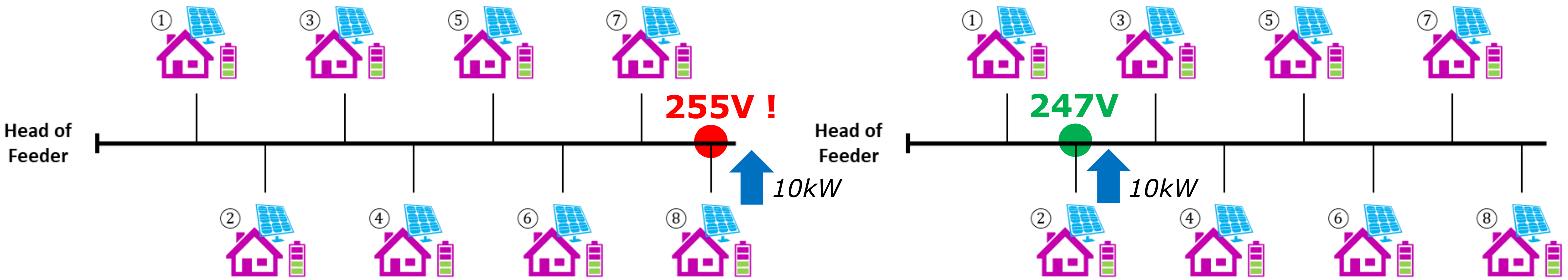
Key Differences

Near Real-Time Architecture	**In-Advance** Architecture
Does not rely on advanced forecasting techniques	Requires adequate forecasts (at NMI level)
The shorter the intervals (e.g., minutes) the more accurate the OEs	The larger the horizon the lower the accuracy for the distant intervals
Requires operationalising key measurements	Less operationalisation, less infrastructure upgrades
More challenging for aggregators to manage their DER portfolio (?)	Easier for aggregators to manage their DER portfolio (?)

Topic 2:
Objective Functions
(Allocation Methodology)

Locational Effects in Radial Feeders 1/2

- Not every kW is equal in voltage constrained networks
  - Farther away → larger impedances → more prone to voltage issues

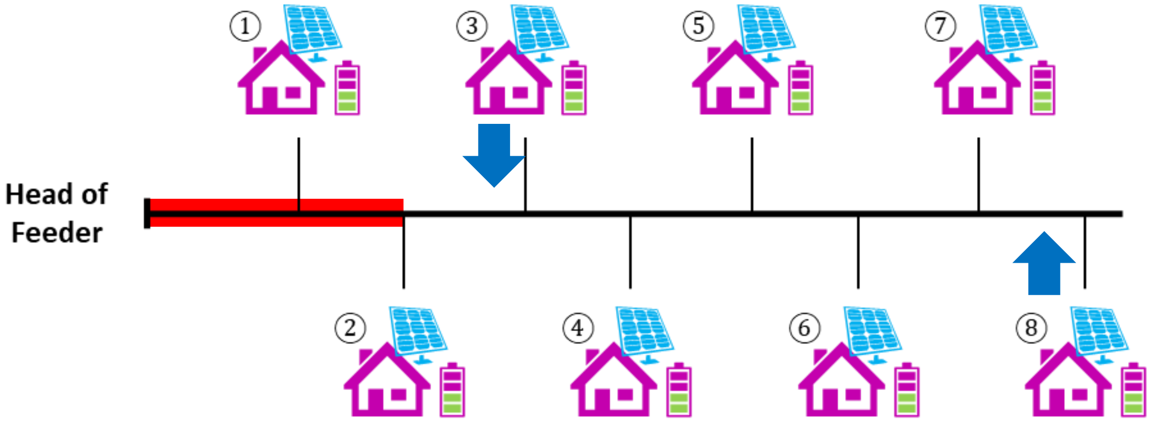


Achieve **maximum total services (exports)** → favour **customers closer to head of feeder**.

Guarantee **equal opportunity** → expect **lower volume of services**.

Locational Effects in Radial Feeders 2/2

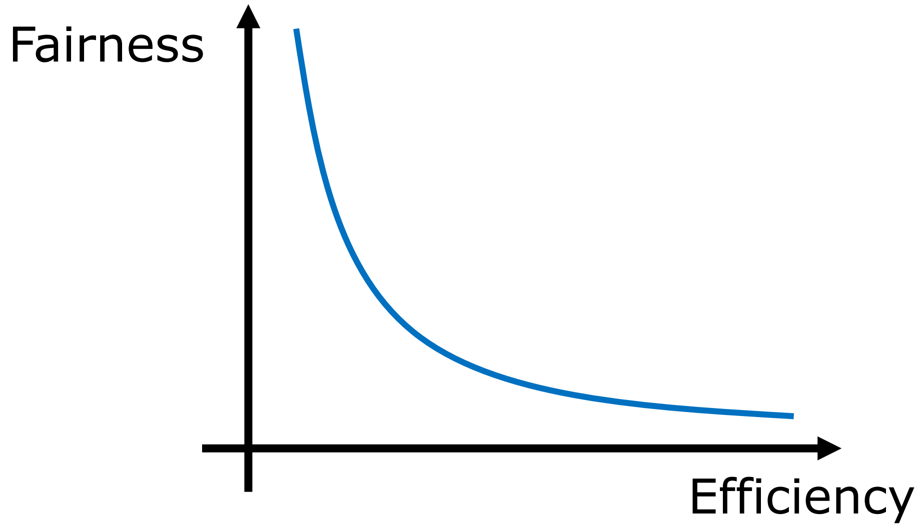
- Similar effects are <u>negligible for thermal constraints</u>
  - Losses are typically very small



The remainder of this presentation will focus on **voltage constraints**.

Fairness and Efficiency Trade-Offs

- **Fairness**: equality* in operating envelopes (for all active customers)
- **Efficiency**: total volume of services (e.g. power exports) that can be facilitated



An adequate <u>balance</u> between <u>fairness</u> and <u>efficiency</u> is important.

* The same or proportional to the size of DER

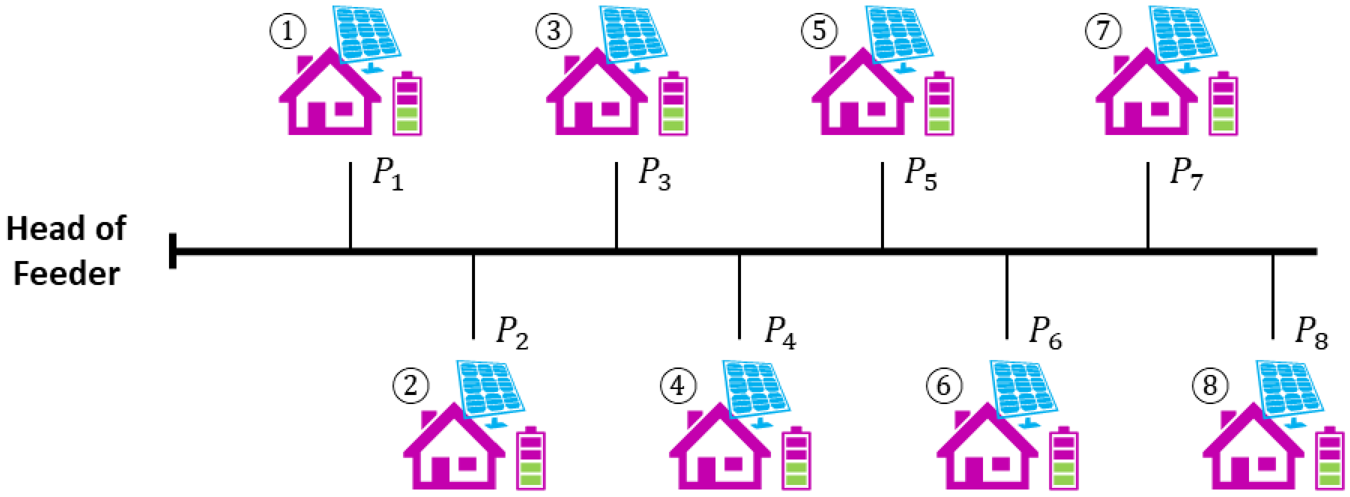
Objective Functions and Principles

- **Objective function**: a set of principles aligned with the vision of the stakeholders
  - The calculation (allocation) of operating envelopes is driven by the objective function

- Example ‘principles’
  - Exploit available network capacity
  - Achieve higher volume of services
  - Provide fair opportunity for all active customers
  - Pursue different priorities (e.g., financial gains)

Three (3) Investigated Objective Functions

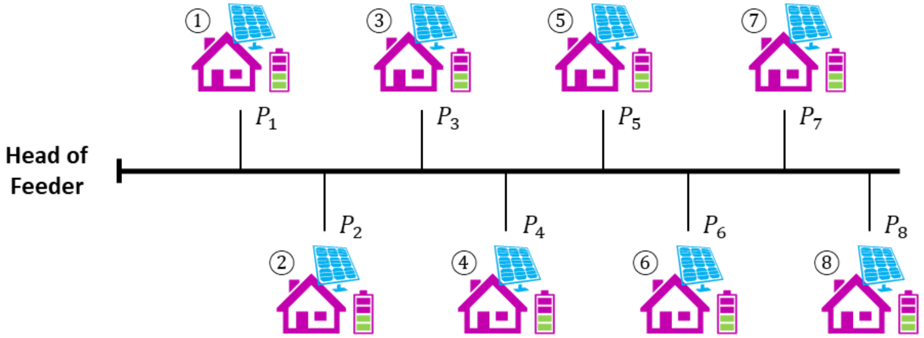
OF1: Total Exports	OF2: Equal Opportunity	OF3: Weighted Allocation
$maximise\ (P_1 + \cdots + P_8)$	$maximise\ (P^*)$ subject to $P^* = P_1 = \cdots = P_8$	$maximise\ (\alpha_1 P_1 + \cdots + \alpha_8 P_8)$



Case Study Setup

- Network
  - Single-phase LV feeder with eight (8) active customers
  - Impedances / distances based on Hume 1 Site B
  - Each active customer has 8 kW available capacity for exports (from their batteries)
  - Head of feeder voltage at 1.055 pu (422V line-to-line)

- OF3 weighting factors
  - $maximise\ (1 \cdot P_1 + 1 \cdot P_2 + 1 \cdot P_3 + 1 \cdot P_4 + 1 \cdot P_5 + 3 \cdot P_6 + 3 \cdot P_7 + 3 \cdot P_8)$

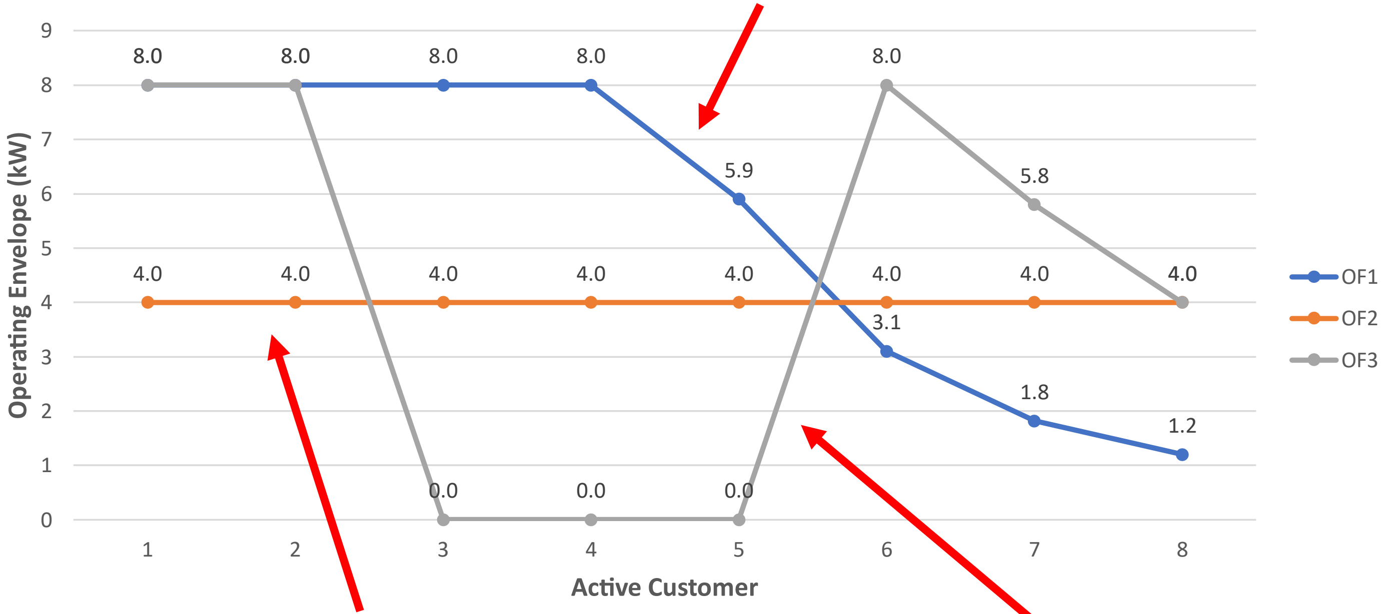


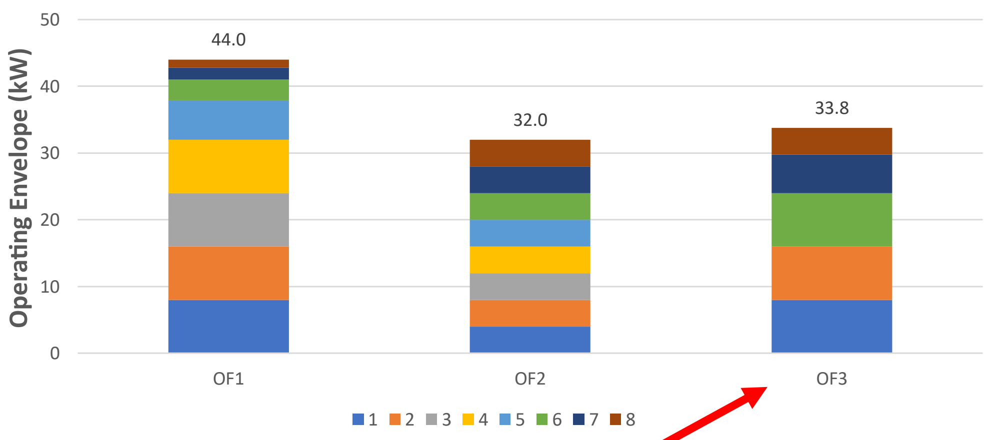
Results: Operating Envelopes

- Note: ‘operating envelope’ and ‘power exports’ are used interchangeably

OF1 favours the first 4 customers.

OF1 has the largest total exports.





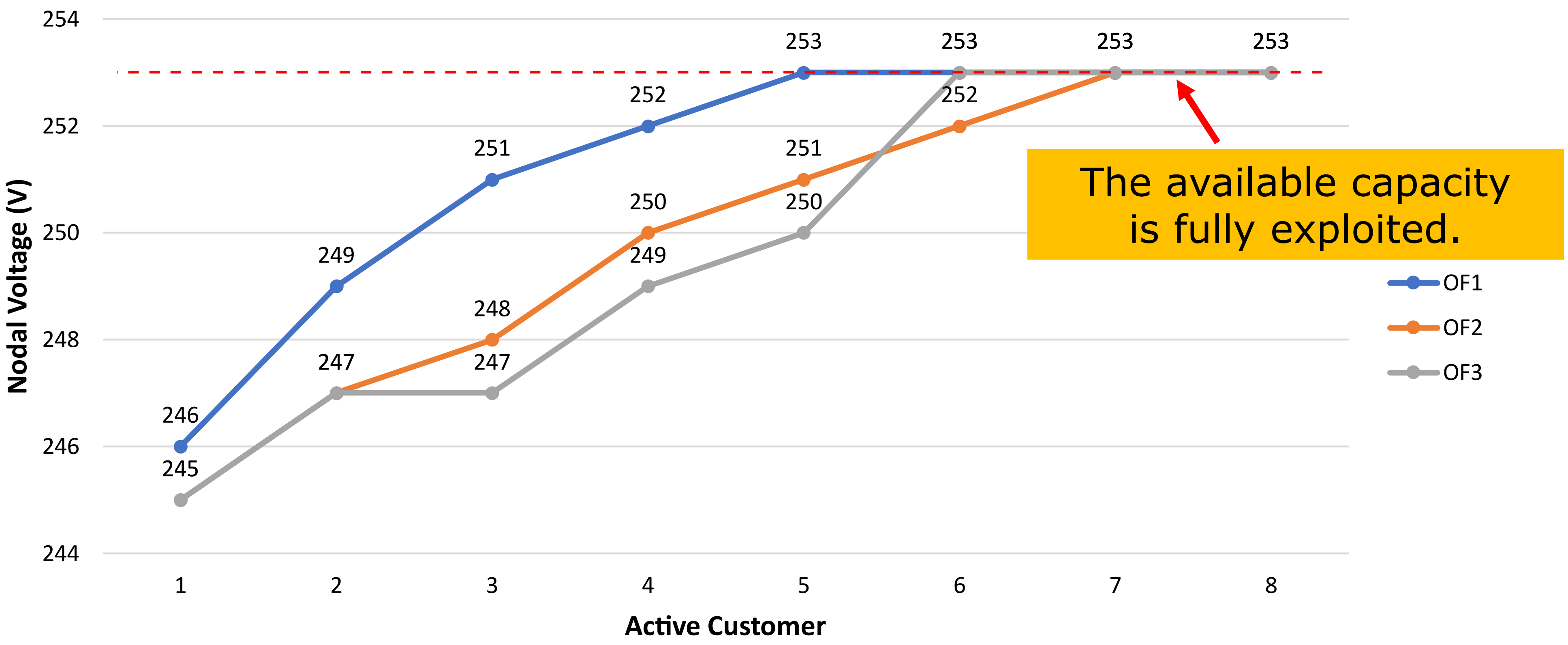
No disparity with OF2.

Drastic effects from the weighting factors in OF3.

OF1: Total Exports / OF2: Equal Opportunity / OF3: Weighted Allocation

Results: Customer Voltages

- Resulting voltages if each active customer fully utilises the operating envelope



OF1: Total Exports / OF2: Equal Opportunity / OF3: Weighted Allocation

Remarks on Performance

	Benefits	Drawbacks
OF1: Total Exports	Higher power exports	Penalises certain customers (closer to end of feeder)
OF2: Equal Opportunity	No disparity in operating envelopes (i.e., fair)	Lower total exports
OF3: Weighted Allocation	Pursue other preferences or measures of performance	Defining weighting factors is not a trivial task

Understanding the pros and cons of each objective function is crucial.

Other Considerations

- Information on active customer bids → 'better' operating envelopes
  - However, this also introduces additional complexity
- Operating envelope ≠ aggregator operation
  - Aggregator(s) may decide to inject at a lesser value
- Some fairness considerations can be beneficial
  - "Don't put all your eggs in one basket."

Everything becomes even more complicated in <u>three-phase</u> networks!

Summary

Topic 1: Calculation Architecture

- **Input data** heavily <u>influences</u> the adopted **architecture**, and vice versa
  - Near real-time: less reliant on forecasting, needs to operationalise measurements
  - In-advance: requires effective forecasting techniques at NMI level

Topic 2: Objective Functions (Allocation Methodology)

- **Efficiency** (volume of services) favours customers closer to the head of feeder
  - Customers less prone to voltage issues can inject more active power
  - This is already seen in PV inverters (Volt-Watt function)
- Improving **fairness** (ensuring equal opportunity) among multiple customers inevitably reduces the overall efficiency
  - <u>More</u> active power from customers prone to voltage issues means <u>much less</u> from others

Further Reading

- Topic 1: OEs and Calculation Architecture
  - "DER and Network Integrity: Meter-Level Operating Envelopes", IEEE Smart Grid Webinar, Dec 2020 (Link)
  - "Impacts of price-led operation of residential storage on distribution networks: An Australian case study", IEEE PES PowerTech 2019, Jun 2019 (PDF)
  - "Managing residential prosumers using operating envelopes: An Australian case study", CIRED Workshop 2020, Sep 2020 (PDF)
  - "Assessing the effects of DER on voltages using a smart meter-driven three-phase LV feeder model", Electric Power Systems Research, Dec 2020 (PDF)

- Topic 2: Objective Function (Allocation Methodology)
  - "On the fairness of PV curtailment schemes in residential distribution networks", IEEE Transactions on Smart Grid, Sep 2020 (PDF)
  - "Operating envelopes for prosumers in LV networks: A weighted proportional fairness approach", IEEE/PES Innovative Smart Grid Technologies ISGT Europe 2020, Oct 2020 (PDF)